CHAPTER 10

ELECTRICAL SYSTEMS

10-1. General electrical design

This chapter provides criteria for the design of highly reliable electrical power systems to serve C4ISR sites. Electrical systems shall comply with the current edition of NFPA 70 and shall be designed so that all components operate within their capacities for initial and projected loads.

a. Electrical peak power demands shall be determined for the specific C4ISR site. Demands shall be calculated based on the total connected load and conservative use of demand and diversity factors between different equipment, systems, and facilities to ensure that adequate capacity shall be available to supply the equipment installed initially and any anticipated future loads. For large systems, a load-shedding and restoration scheme shall be provided to compensate for sudden changes in available power caused by loss of any commercial (prime) power source, by loss of one or more on-site (standby) generating units, or by loss of both power sources. Typical site operational load will generally consist of a technical load, an emergency load, and a non-essential load. See figure 10-1.

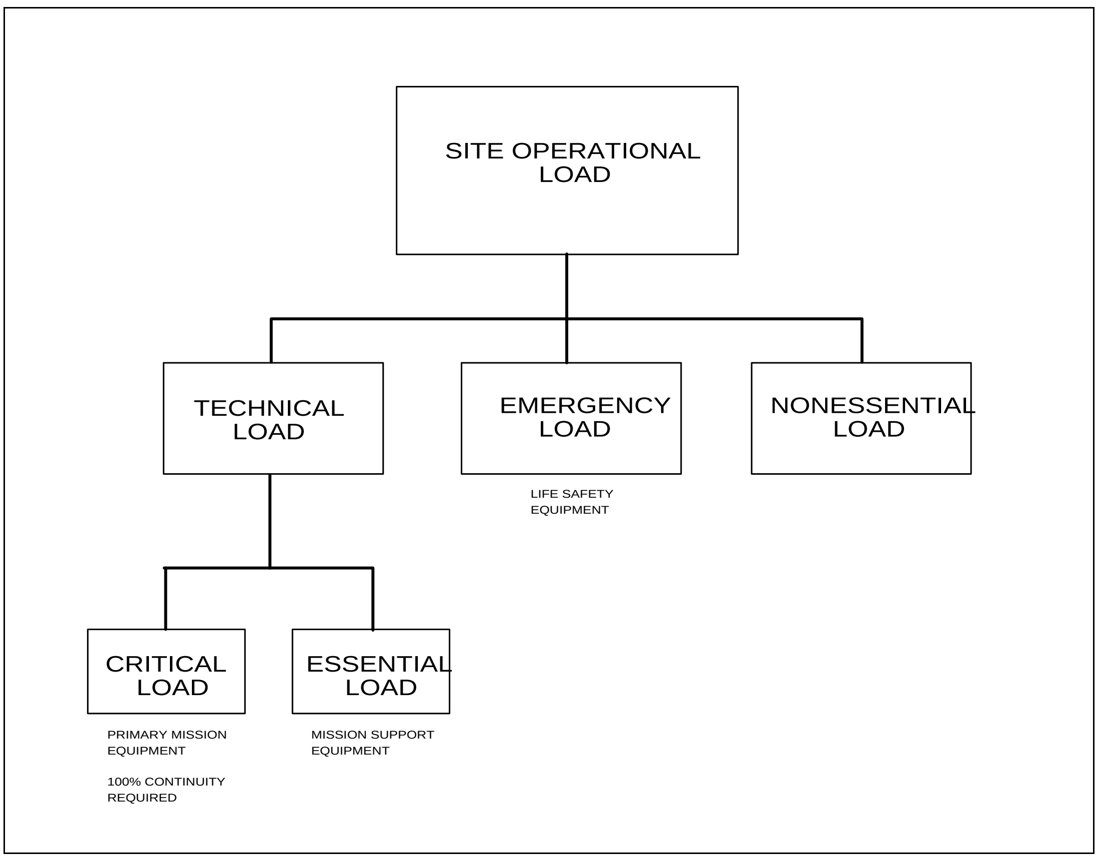

Figure 10-1. Hierarchy of electrical loads

(1) Critical loads are that portion of the technical load used to successfully accomplish the site missions and having a requirement for 100 percent continuity in power service, such as from the UPS

system. These loads also include any equipment which, upon loss of power, will create an unacceptable impact on the mission or mission equipment. These loads shall not be shed intentionally if sufficient power is available to supply them. Less critical loads can be shed manually in instances when sufficient power is not available to supply all critical load demands. Critical loads shall be restored first if there is a total power outage and as soon as possible after partial or total power is restored.

(2) Essential loads are that portion of the technical load that directly supports routine accomplishment of site missions. Loads include general lighting and power systems; heating, ventilating, and air conditioning (HVAC); and similar loads which can tolerate short-term power outages without loss of data or without adversely affecting vital missions. All systems other than the critical equipment/systems (CES) are to be considered essential if they must operate to supply CES directly. This includes the support loads for the critical loads, security lighting, intrusion detection, entry control, and security monitoring equipment. These load types shall be shed second and restored before non-essential loads, but not before the critical loads are restored if power to critical loads is also lost.

(3) The emergency load consists of emergency lights, exit lights, fire suppression systems, and similar life-safety loads. Emergency loads shall be provided with their own battery backup systems or emergency generator capable of coming on-line within ten seconds. These loads shall not be served from the UPS supplying critical loads.

(4) The non-essential load is that portion of the operational load that indirectly supports the operations at the C4ISR site. This generally includes exterior and interior lighting and loads associated with administration and housing functions. Non-essential loads shall be shed first and restored last during power shortages and restoration of power. The design of the power system for non-essential support systems uses radial feeders and non-redundant items of equipment. Conventional design practice shall be followed, with the possible exception of the use of additional relaying.

b. Three types of electrical power systems are utilized to supply the C4ISR facilities identified in paragraph 1-2. These vary in size and the type of equipment installed within as noted.

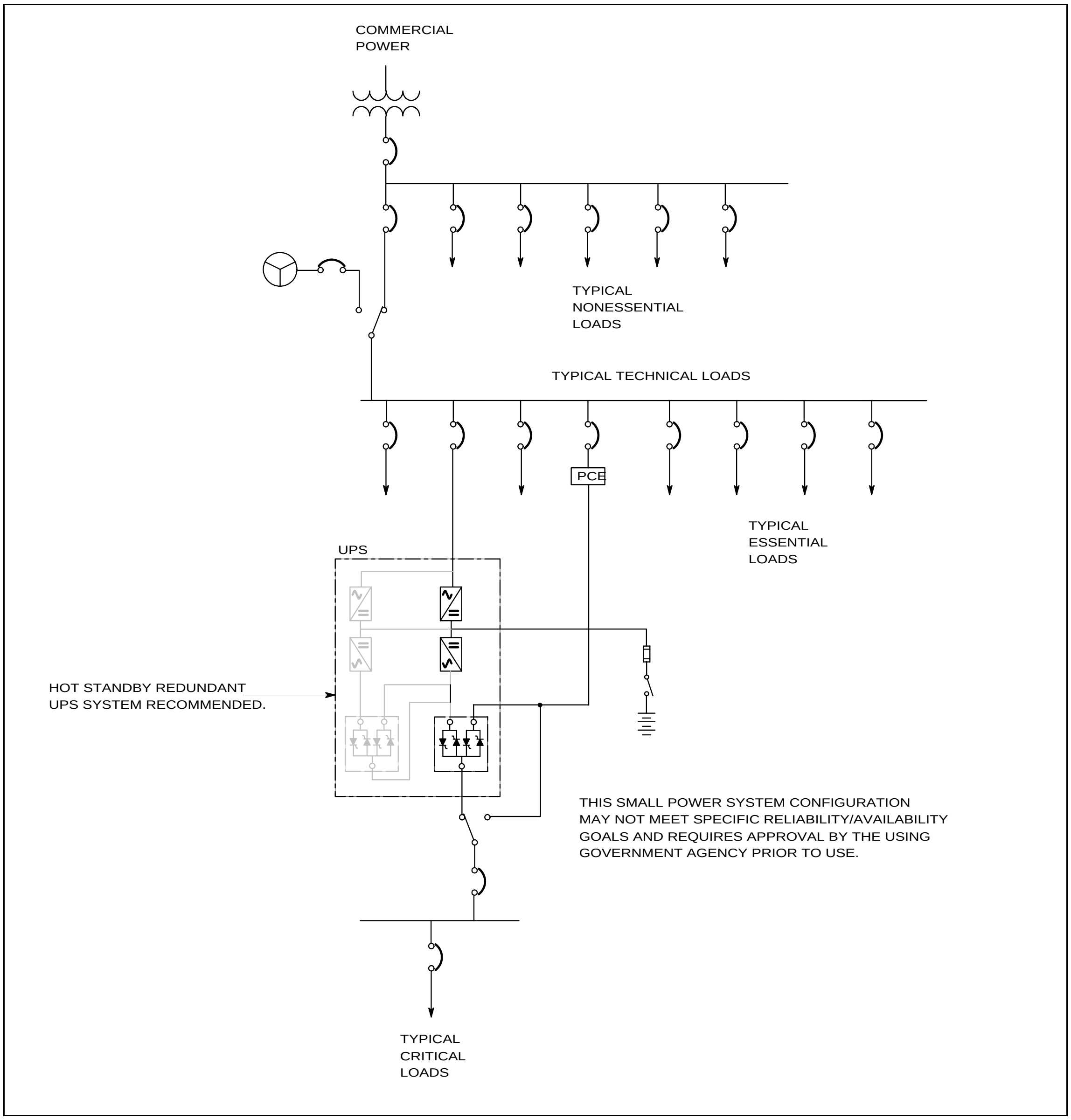

Figure 10-2. Small capacity power system

(1) The small capacity system (less than 250 kVA) is typically used to supply power to a remote data and/or telephone switch site. Such a system would generally utilize a service transformer supplied from one off-site power source and a single standby diesel or natural gas generator. Equipment inside would consist of a small rectifier for a 48 VDC bus, a small inverter, and several distribution panels. Note that because the small capacity system described herein may not meet the stringent reliability/availability (R/A) goals outlined elsewhere in this document, the AHJ should require a second standby generator for critical facilities. See figure 10-2 for a suggested configuration. The power conditioning equipment (PCE) shown in the figure may represent any number of methods commonly used to isolate critical loads from line disturbances, such as an isolation transformer, power conditioner, or motor-generator (MG) set. Use of a hot standby redundant UPS system (one in which the backup module is continuously energized and prepared to assume the critical load if the normally available UPS should fail) should also be considered.

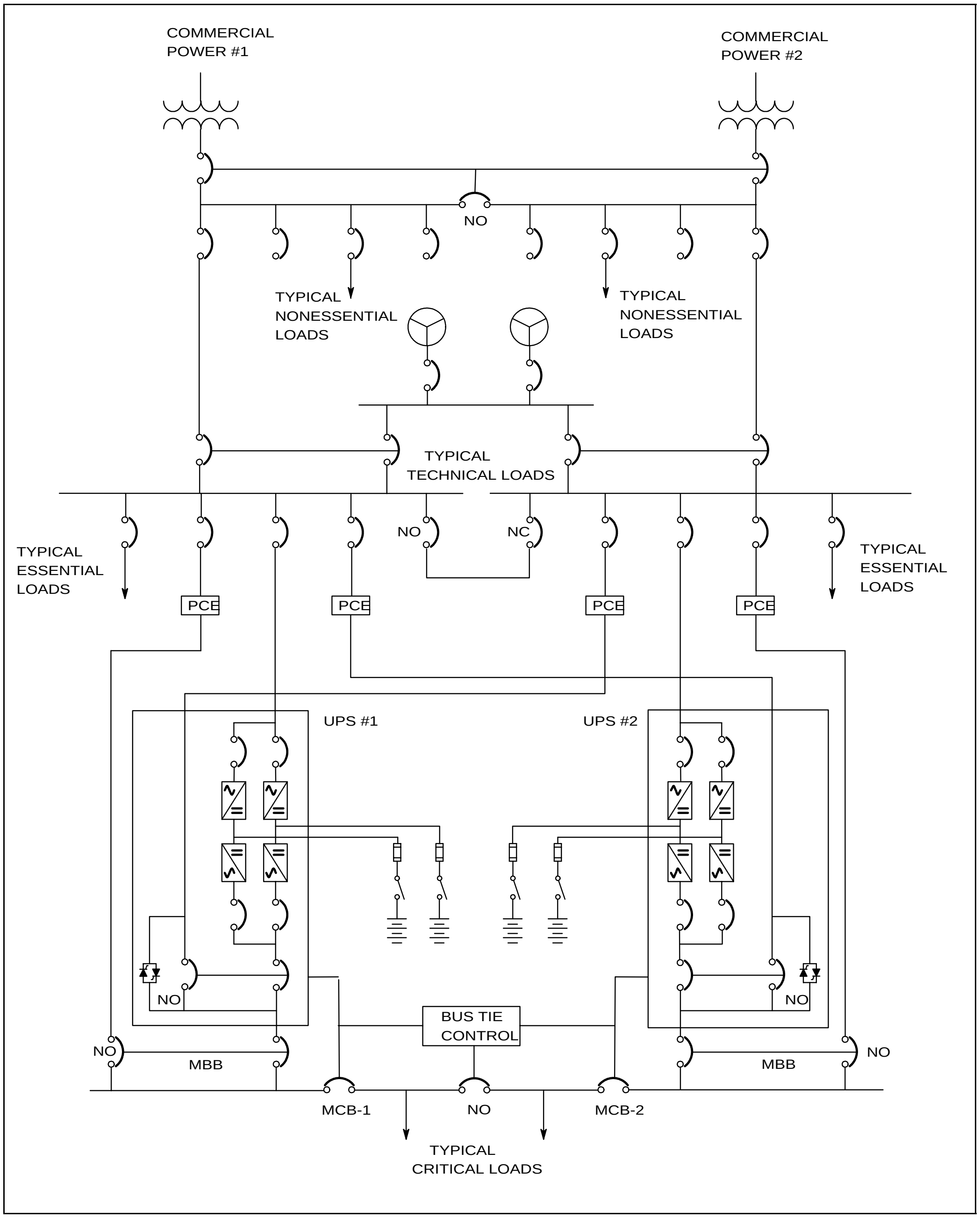

Figure 10-3. Medium capacity power system

(2) The medium capacity system (generally up to 2500 kVA) will support a main computer facility by utilizing one or two pad-mounted service transformers with primary selective feeders to the facility from the off-site power source. This system would utilize two low-voltage paralleled standby diesel generators, paralleling switchgear, and one or two large UPS systems. The main computer room would have numerous power distribution centers that supply conditioned power to the load. See figure 10-3 for a suggested configuration.

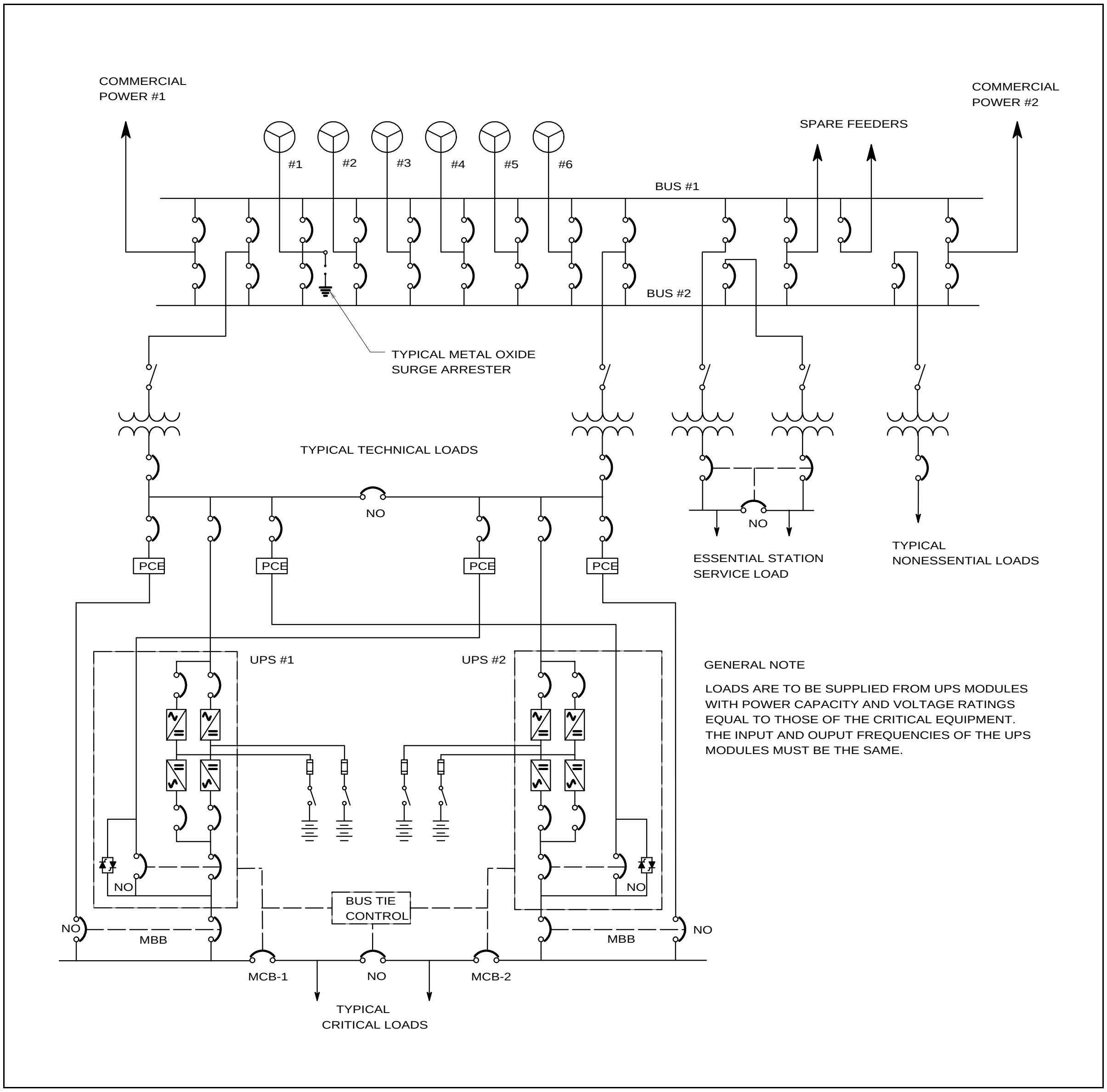

Figure 10-4. Large capacity power system

(3) A multi-facility site consisting of several installations will require a central power plant for supplying power to all of the buildings within the site. This large capacity power system (10 MVA or greater) will employ double-ended substations, paralleled medium voltage standby diesel generators, and large UPS systems. For example, the plant may contain five 2000 kW 4.16 kV (or 13.2 kV) diesel engine generators available for standby power. Each of the two transformers would be rated 5-10 MVA at 34.5 – 4.16 kV. See figure 10-4 for a suggested configuration.

10-2. Electrical systems maintenance

The C4ISR power system shall be designed to facilitate maintenance. Preventive and routine maintenance will be performed by the operating crew without removal of components from their normal operating locations, except for equipment designed for removal and testing, such as power circuit breakers and protective relays. Support maintenance will be performed at an on-site maintenance facility by the site maintenance crew. During the off-site power mode of operation, off-site logistical and maintenance support is assumed to be available. During the on-site power mode of operation, only on-site logistical and maintenance support will be available. Corrective maintenance will be performed as necessary and with minimum impact on site operations. A minimum of a 30-day supply of site consumables, to be supplied by the using government agency, is required for on-site operation.

10-3. Power quality

Electrical loads at C4ISR sites may include extremely non-uniform and harmonic-producing equipment such as the transmitter for phased-array radar, UPSs, motors, IT and communications equipment. These loads can cause severe voltage wave form distortion and adversely affect generator set controls, protective relaying, and other connected equipment.

a. The site power distribution system shall comply with the table, "Standard Nominal System Voltage Ranges," presented in American National Standards Institute (ANSI) C84.1, Electrical Power Systems and Equipment – Voltage Ratings (60 Hertz). The commercial power service should meet and the on-site generated power shall meet the requirements of "Service Voltage" limits listed in ANSI C84.1. Site power distribution conductors shall limit voltage drops to values compatible with the "Utilization Voltage" limits listed in ANSI C84.1.

b. The design agency shall be required to show proper values for kilowatts, kilovolt amperes, and other variables related to frequency when the C4ISR site or project is to be served by a power source having a standard frequency different than 60 hertz.

c. A thorough analysis of the site loads, including load flow, transient motor starting, harmonic, and dynamic stability studies, shall be performed only for the large capacity systems employing multiple diesel generator units. Additionally, short circuit, coordination, and lightning protection studies shall be performed for both the small and large capacity power systems. Information and/or recommendations from the equipment suppliers must be obtained, and a variety of design techniques involving system configuration, generator set selection, and filtering of power and control circuits may be required. Use of power-conditioning equipment (PCE) shall be considered to minimize the risk of damage to critical loads resulting from the transients and unacceptable regulation common to utility power systems.

d. When it is determined from the electrical load analysis that the voltage total harmonic distortion (THD) will be greater than 5 percent, or that any individual frequency voltage harmonic will exceed 3 percent of the fundamental, the power system shall be stiffened. Use a separate neutral conductor for each branch circuit and minimize the use of shared neutral conductors. Evaluate the installation of an active harmonic filter. The following are acceptable methods for stiffening the power system.

(1) Increasing the transformer sizes

(2) Increasing the sizes of phase conductors and neutral conductors with neutral conductors being the larger.

(3) Adding additional transformers and conductors, limiting the length of conductors and using additional transformers with tap changing capability when the voltage drop is larger than that recommended by NEC.

(4) Redistributing loads to balance load currents (as well as harmonics in all phases of the three-phase system)

e. Equipment shall be ordered to Institute of Electrical and Electronics Engineers (IEEE) 519, IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems, specifications or to meet other relevant industry standards that limit the generation of harmonics. Loads that are sensitive to harmonics shall be isolated from those that produce harmonics by use of isolating transformers, motor-generator sets, or UPS. A periodic inspection, at least yearly and particularly after any change in system configuration is made, shall be conducted to assess harmonic-related problems.

f. The electrical power system shall be designed to enable the continuous on-line monitoring of electrical power to critical loads. Parameters monitored shall include voltage, current, frequency, harmonics, noise, and voltage transients.

g. Documentation of the systems design will be completed utilizing standard computer-aided drafting (CAD) procedures.

10-4. Off-site electrical power

Off-site commercial or utility power sources shall be used when available. Any commercial power source considered shall have an adequate quantity of power to supply the site operational load. For both large and medium capacity power systems, two separate commercial power sources are preferred to supply the C4ISR site primary substation(s). When two separate sources are not available, a single commercial power source should be used to supply redundant transmission lines to the site. The redundancy shall be provided through two or more full capacity circuits supplied from normally isolated switchgear buses in the power provider’s substation. Small capacity power systems will generally be supplied by a single distribution feeder from the commercial power source. Design of the off-site power supply, the power distribution system, and the on-site generating power system shall permit scheduled outages for maintenance, repair, or testing of equipment or materials without significant impact on the C4ISR site missions. Independence and R/A of the off-site power source(s) shall be maximized through contractual arrangements with the commercial power company or companies. When off-site power is used exclusively, the on-site power supply shall be on standby. The availability of this mode shall be calculated.

a. A survey shall be conducted to determine the availability of commercial power sources in the vicinity (ten miles or less) of each new C4ISR site, and an evaluation shall be made with regard to past R/A history (power outage frequency, duration, etc.). The R/A history of each available source shall be a prime criterion in selecting the preferred line, which shall be rated not less than 15 kV. Use of two widely separated commercial power lines is recommended in preference to use of a single line, but the decision to use a second source, when available, shall be made on a site-specific basis by the using Government Agency. If two commercial power sources are used, the C4ISR site primary substations shall be located as far apart as practical, but reasonably close to the on-site power supply for the C4ISR site. TM 5-811-1, Electrical Power Supply and Distribution, chapter 1, contains design guidance for the primary substation.

b. The contract with any commercial power company shall be based on single-point, primary metering and shall allow for the paralleling of on-site generating units with the commercial power line or lines at the discretion of the C4ISR site operating contractor. The contract shall require the company to maintain power to the site continuously, regardless of other power demands on the transmission system. The contract shall also specify the maintenance responsibilities of the commercial power company. Recommended responsibilities of the commercial power company include regularly scheduled maintenance of commercially owned lines and equipment necessary to ensure continuous service.

c. Figure 10-5 shows typical equipment and relaying for a C4ISR site primary substation supplied by a single commercial power line, and should be referenced in relation to the following design guidance.

(1) Line switches designated as switches 1, 2, and 3 on figure 10-5 shall be the group- or gang-operated type of air switches for isolation of the line circuit breaker and for bypassing that breaker when it is out of service for maintenance. Consideration shall be given to the use of a fused bypass switch unit to protect the transformer against faults when the line circuit breaker (LCB) is out of service.

(2) Consideration shall be given to the use of SF6 type breakers. The use of the circuit-switcher type of protective device shall be approved by the using government agency or its technical representatives.

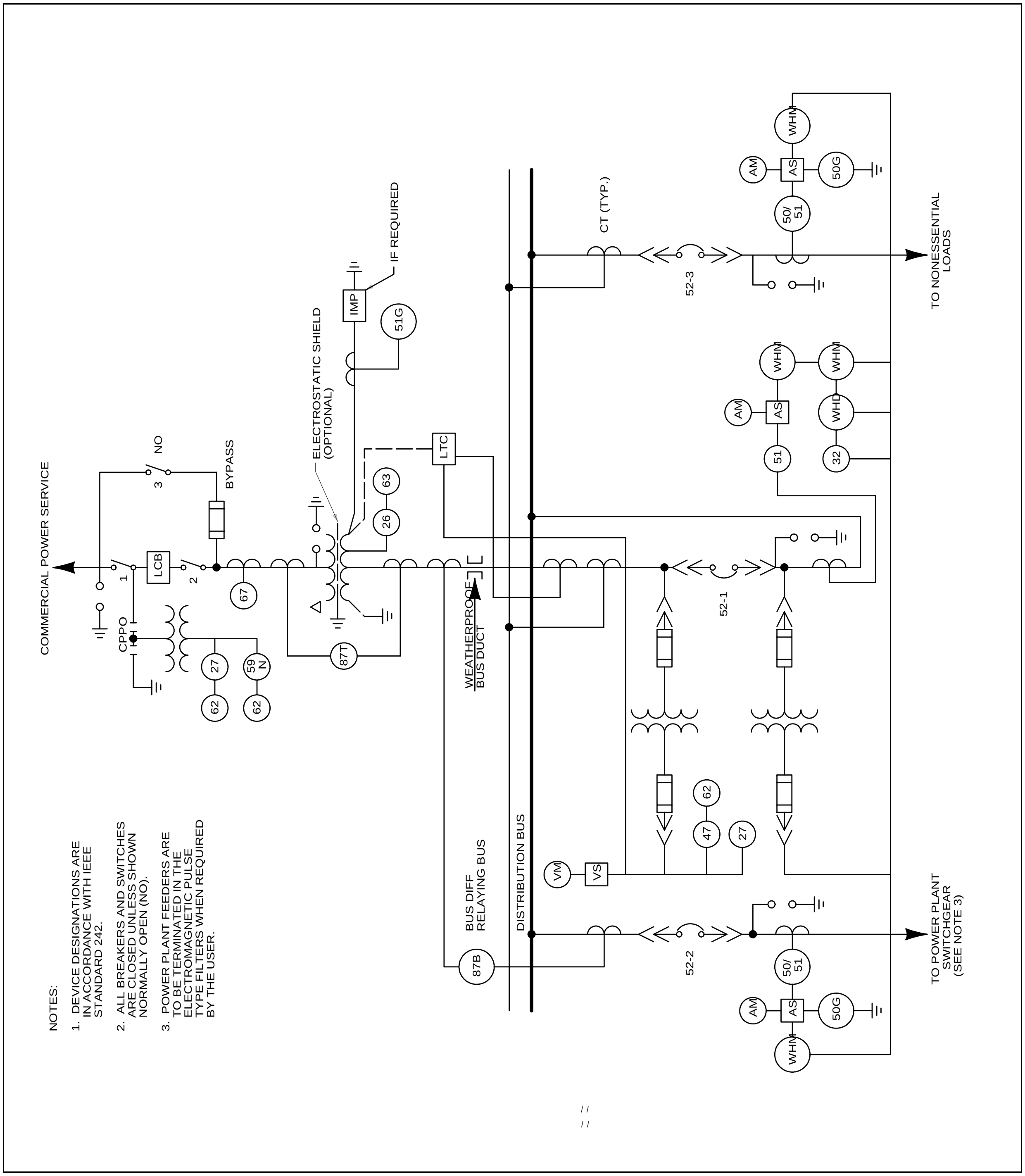

Figure 10-5. C4ISR site primary substation

(3) Power transformers installed at the primary substation shall comply with the following criteria.

(a) The voltage rating shall be consistent with the nominal voltage rating of the commercial power line and with the nominal voltage rating of the site power distribution system. The kilovolt ampere rating shall be sufficient to supply the peak demands of the C4ISR site technical facilities and any non-essential support facilities continuously without exceeding the 65°C (149°F) thermal rating in an ambient temperature typical to the site of installation. The transformer(s) shall contain delta primary windings and wye secondary windings with neutral connection tap provided for use as either a direct ground or a resistance ground connection. The transformer shall have provisions for the future addition of fans. If a double-ended substation is used, the kilovolt ampere rating may be reduced to 90 percent of the peak site demands, but the transformer shall be equipped with one stage of fans, with provisions for the future addition of a second stage of fans.

(b) Large power transformer(s) may be equipped with an automatic load tap changer (ALTC) to maintain adequate voltage regulation if the power system load profile and configuration so warrant. If two or more transformers are required or selected during design, the ALTC shall include cross-current compensation. The ALTC shall have sixteen 0.625 percent taps above and sixteen 0.625 percent taps below the nominal voltage rating of the secondary windings of the transformer. The ALTC control system shall have line drop compensation to account for the voltage drop along the transmission line(s) supplied by the power transformer. The controller shall have adjustable bandwidth (i.e., error limits) and setpoints, and an adjustable control voltage range (110-130 volts).

(c) The station class of metal oxide type arresters shall be installed at the high-voltage terminals of the transformer. The same type and class of arresters shall also be installed at the medium-voltage terminals of the transformers if aerial conductors are used to interconnect the transformer with the switchgear bus or buses.

(4) Circuit breakers shall be the vacuum type and shall be protected by the metal oxide type of surge arresters. Instruments, relays, and control devices shall be mounted on the front of the associated breaker or auxiliary units. Consideration shall be given to the proper ventilation or air conditioning of the metal-clad switchgear and to the installation of a spare circuit breaker equivalent to the breaker having the largest load rating.

(5) The relaying and control scheme shall make possible the clearing and isolation of faults and the separation of C4ISR technical loads from the commercial power source during faults or abnormal operating conditions on the commercial power line. A short circuit protection and coordination study shall be made by the design agency. The coordination study shall demonstrate that protective devices in the primary substation switchgear will properly coordinate with each other, with relaying used by the commercial power company, and with relays to be installed in the site’s low- and medium-voltage switchgear assemblies.

10-5. On-site power generation equipment

To ensure an optimal degree of reliability of on-site generating units during actualization of threats, the commercial power source shall be utilized to an optimal extent during normal operating conditions at the C4ISR site. The characteristics and quantity of power to be supplied by on-site generating units will depend on the type of equipment (which is determined by mission requirements), the criticality of such equipment, and the different types of facilities or projects to be designed and constructed. Operational on-site units shall be capable of supplying the peak site demands while operating independently of any commercial power source when loaded between approximately 60 and 80 percent of their rated load capacities. Loading of active generating units shall not exceed these percentages. For large capacity power systems, the total number, "T", of on-site generating units required to supply the peak power demands and to ensure that the minimum availability goal is achieved shall be computed using the formula T = N + 2. "N" is the number of on-site generating units required to supply the peak power demands at between 60 and 80 percent of their rating and 2 is the required number of redundant units. (One unit is required for backup and one unit is required for maintenance outages.) For medium capacity power systems, the formula T = N + 1 shall be used. The long term and defined mission time reliability indices of the system shall be calculated for the on-site mode. The availability of the system for the off-site/on-site power mode shall also be calculated.

a. For on-site power generation, the power plant shall contain stationary prime mover generator sets and associated ancillary and control systems. TM 5-811-6, Electric Power Plant Design, contains design guidance for selecting sizes of generating units. Any generator supplying the minimum C4ISR facility demand shall be designed to be loaded to at least 50 percent of the kilowatt rating. The C4ISR on-site power plant for large capacity power systems shall be capable of making the transition from the off-site to the on-site power mode of operation in not more than three minutes, including starting and synchronizing a sufficient number of generator units to serve the technical load. Specific applications may require a shorter starting time, particularly for medium and small capacity systems or for generator(s) supplying life safety loads. On-site power units shall be capable of being started using only on-site equipment and facilities. All generators (including standby units) shall be continuous duty rated.

b. Generators shall be specified in accordance with ANSI C50.10, Rotating Electrical Machinery-Synchronous Machines, and National Electrical Manufacturers Association (NEMA) MG 1, Motors and Generators, standards as minimum requirements. The generator sets for large systems shall be capable of parallel operation with a commercial power source and with each other. The generator windings shall be three-phase, wye connected, with neutrals brought out for external connection.

(1) The generator voltage shall be the highest standard voltage commensurate with the load served and the electrical distribution system characteristics. NEMA standard voltages shall be used except where special conditions prevail. The frequency shall be 60 hertz unless the C4ISR site is located in an area where 60 hertz is not standard.

(2) The static type of exciter-voltage regulator shall be used for generator field excitation for all generators rated 1,000 kVA or larger. A static exciter-voltage regulator shall also be used for generators smaller than 1,000 kVA except when brushless exciters are customarily furnished with those sizes and deviation from the manufacturer's standard design would result in excessive costs. If brushless exciters are used, they shall be the series boost type.

(3) At any lagging power factor from 0.8 to 0.96 as the steady-state load increases from 0 to 100 percent of rated generator capacity, the exciter and regulator combination shall maintain voltage stability within the limits specified in paragraphs (a) and (b) below.

(a) The voltage variation at any steady-state load from 0 to 110 percent of the generator capacity shall be within 0.5 percent of the rated voltage. The term "steady-state variation" is defined in the glossary at the end of this manual.

(b) Transient voltages shall not exceed 5 percent after a 25 percent step change in load. The voltage shall recover to nominal voltage ±0.5 percent within one-half second after initiation of the load change.

(4) The governor shall maintain a constant speed within ±0.25 percent for any constant load between one-fourth and full load kilowatt rating of the generator. After any sudden load change of not more than 25 percent of the rated load, the transient speed deviation shall not exceed ±3.0 percent, and the governor shall re-establish stable operating conditions in not more than three seconds.

c. The generator set control system for large capacity power systems shall permit use of both automatic and manual procedures for startup, synchronization, and loading to either switchgear bus. The automatic synchronizers, load-sharing and speed controls, and actuators shall be compatible with each other and with the automatic procedure, while manual speed and load control switches shall preserve the option of manual control. One synchroscope and associated "incoming" and "running" frequency and voltage meters, synchronizing lamps, and switches shall be provided for each of the two switchgear buses. The design shall also include a selector switch which will permit automatic or manual synchronizing of generators to either switchgear bus.

(1) A time control unit shall permit accurate timekeeping and serve as a frequency standard when the on-site generator sets are operating in isolation from the commercial power company. The time control unit shall have at least as many outputs as there are generating units in the plant. The time control unit shall automatically correct for cumulative time errors.

(2) The control system shall include an automatic load-sharing control system. Load trimmers or controllers shall be provided for elimination on inequalities in generator loads. The system shall smoothly adjust the load on an incoming unit to its proportional share of the total bus kilowatt load.

(3) A reactive differential compensator shall be provided for automatically equalizing the volt-amperes reactive (VARs) supplied by each on-site generator. The compensator shall include the voltage regulator for each generator and cross-current compensation current transformer which senses the phase currents of each operational generating unit.

(4) This unit shall control the inflow of power from the commercial power company to the on-site power plant switchgear buses. This power flow shall be held to a desired level either remotely by a signal converter in the control room (CR) or as set by a potentiometer located on the power plant switchgear. The power interchange control unit shall have high- and low-limit settings to prevent the generators from becoming overloaded or from being motored by the utility company.

(5) Provision shall be made for automatic flashing of generator fields at the time of generator set startup, using a power plant station battery as the dc power source. UPS batteries shall not be used for this purpose. If a static exciter is specified, the design shall show provisions for automatically disconnecting the field-flashing circuit when each "incoming" generator attains 90 percent of rated speed.

(6) Automatic sequence control equipment shall be provided to startup, synchronize, load or unload, adjust the reactive load of units, and to shut down units in the selected order.

d. For large generators (over 12.5 MVA) a low-voltage power circuit breaker, electrically operated under control of the generator set automatic sequencer and relays shown on Figure 10-6, shall provide the generator field protection. Fuses are typically used to provide field protection on smaller generating units.

e. Figure 10-6 illustrates a typical arrangement of generator protective relaying. IEEE 242, IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems, shall be used as a guide for design. Typical generator protection shall be provided for units rated 0-500 kVA above 5 kV, 500-1,000 kVA above 2.4 kV, and greater than 1,000 kVA regardless of the voltage rating. Protective devices shall respond to the true root mean square (RMS) value of current.

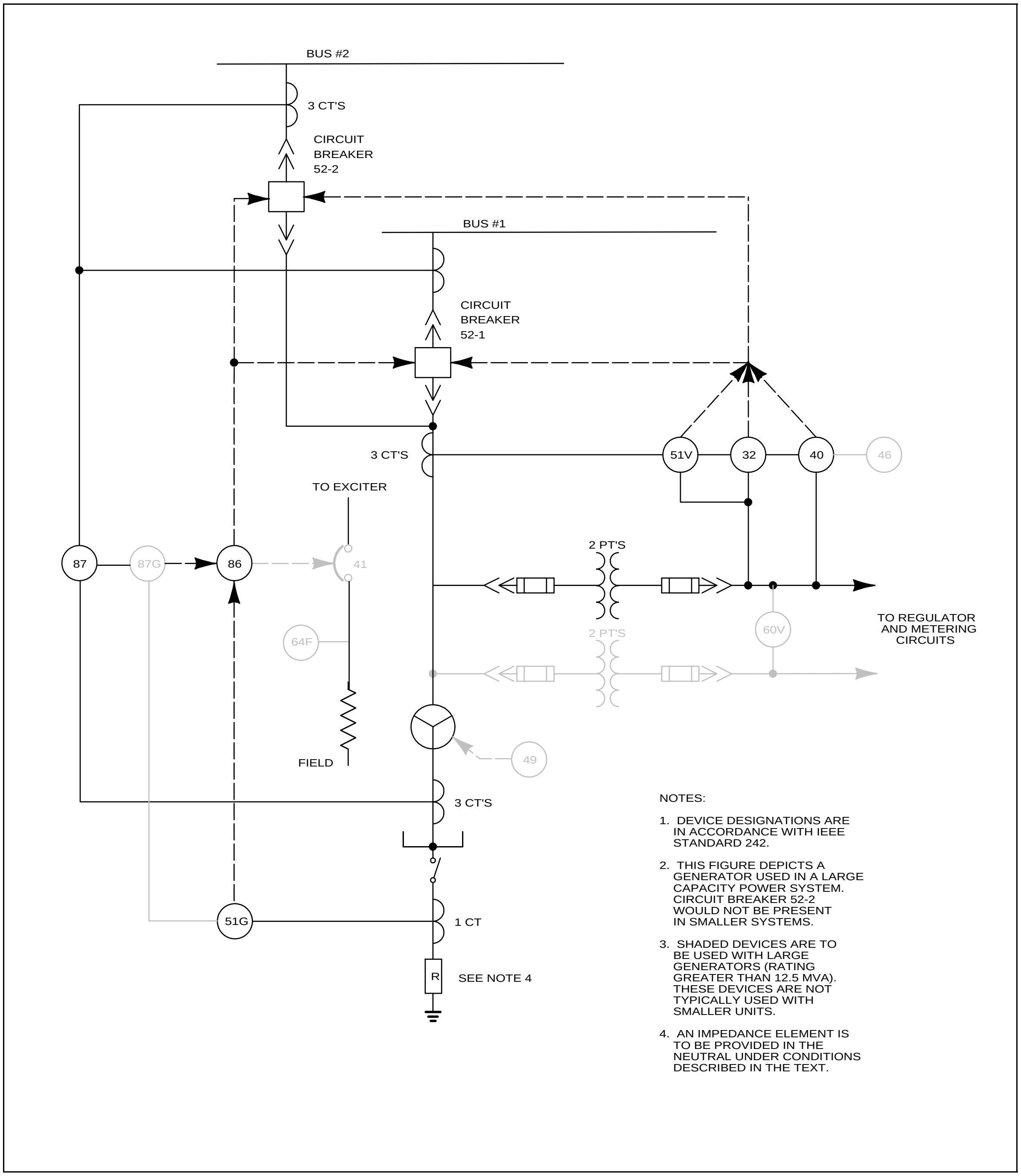

Figure 10-6. Generator protection system

f. Each generator shall be protected against damage from severe voltage transients caused by lightning or switching surges. IEEE 141, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants, states that the standard protective circuit for rotating machines consists of arresters and capacitors located near the machine terminals. The arrester's function is to limit the magnitude of the voltage to ground, while the capacitor decreases the rate of rise of voltage at the machine terminals. Surge arresters shall be connected between ground and each phase conductor, and shall be specified to be mounted on the line side of the circuit breaker as near the generator terminals as possible. The station class of metal-oxide type of surge arresters shall be specified. Vacuum pressure impregnated (VPI) generator windings shall also be specified.

g. Equipment associated with each generator, such as the generator exciter-regulator, neutral breaker, annunciator panels, instrument transformers, instruments, relays, synchronizing devices, and switches, shall be grouped near the generator in or on suitable switchgear enclosures. A remote annunciator panel indicating all alarms shown at the generator control panel shall be provided in an area with 24-hour occupancy. Generator switchgear shall have the ability to connect to an external mobile generator in the event of an emergency.

h. The neutral conductor of each generator shall be grounded either solidly or through an impedance element such as a resistor, reactor, or transformer. The type of grounding shall be determined based on the magnitude of the ground-fault current available from all sources. The rating of the impedance element selected and approved shall be sufficient to prevent damage to the generator and cabling due to ground fault current, but adequate to allow sufficient ground fault current to flow to cause the ground relay to operate and isolate the generator from the power system.

i. Load banks shall be specified if the system is unable to parallel and synchronize with the off-site power supply (typically the case for small and medium systems). Load banks shall have the capacities required to permit system testing of associated generators at approximately 50, 75, 100, and 110 percent of the kilowatt rating of the power plant. If possible, load banks shall be portable. Load banks shall permit testing at a minimum of two power factors. Power factors of 0.8 and 1.0 shall be included.

10-6. Load shedding and restoration

For large capacity power systems, a load-shedding and restoration scheme shall be designed for disconnecting essential and non-essential electrical loads when the capacity of the power source to supply these loads is curtailed or when power service is interrupted. The load-shedding and restoration programs shall provide automatic responses to the different operating conditions.

a. When the C4ISR facility is operating on commercial power only and the supply is interrupted, all loads except those served by Puss shall be de-energized and separated from their power sources. When commercial power is restored, or when on-site generators are operational and connected to the switchgear bus, the loads shall be reconnected in the order of their importance, based on the hierarchy of loads defined in figure 10-1.

b. When the C4ISR facility is operating on on-site power only, partial or total loss of all generators shall result in the partial or total shedding of essential and non-essential loads. If partial loss of generators occurs, loads shall be shed to match the remaining generator capacity until reserve generators can be put on line or the commercial power source can be re-established. In the event of total loss of on-site generating capacity, the commercial power supply, if available, shall be used to minimize the duration and extent of a non-operational condition. If a commercial power source is not available, on-site generating capacity shall be restored as soon as possible after the fault is detected and isolated. The restoration sequence shall be in the order of the load hierarchy defined in figure 10-1.

c. If during parallel operation between commercial power and on-site generators the on-site generators shut down, no load-shedding scheme is necessary. In the event of commercial power failure during parallel operation with on-site generators, the load shall be shed or trimmed automatically to match the capacity of the generators that are on the bus, using the hierarchy of loads defined in figure 10-1.

10-7. Exterior distribution system

Distribution feeders from the C4ISR site primary substation shall be installed in underground ducts whenever feasible. The voltage drop shall not exceed three percent. When the distance between the primary substation and C4ISR facilities makes a conventional underground system an unrealistic option, a feasibility study shall be made which includes a thorough analysis of comparative life-cycle costs and R/A for several options. Two options which shall be considered are: two or more aerial cables containing the three-phase and neutral conductors, and use of a distribution voltage higher than the nominal voltage rating of on-site generators used in conjunction with an exterior substation located at the site.

a. Design requirements for the exterior distribution system shall be determined by the using Government agency after evaluating the result of the feasibility study discussed above. Design guidance for aerial and underground distribution systems is contained in TM 5-811-1, chapter 1, and shall be followed except as otherwise indicated. Distribution feeders shall be terminated at filters to afford protection against high-altitude electromagnetic pulse (HEMP). This requirement shall be considered in any feasibility study conducted.

b. An underground distribution system shall be selected whenever feasible, and shall be installed in such a manner as to dissipate the currents that would be produced by EMP. The number of active feeders and the need for a spare feeder shall be considered based on the limitations in capacity of EMP power line filters, criticality of loads and mission requirements, and the consequent degree of R/A necessary to accomplish the missions successfully. Reliance on continuous or frequent operation of on-site generating units shall be at a minimum. Consideration shall be given to using two or more active feeders to serve separate power distribution switchgear buses under normal operating conditions. If two or more active feeders are to be installed between the primary substation and the C4ISR site, they shall be installed in separate ducts located a sufficient distance apart to prevent a single destructive event from causing physical damage to the two or more active feeders.

c. An aerial distribution system shall be provided between the C4ISR site primary substation and a location near the point of entrance if a complete underground distribution system cannot be justified. To ensure that the R/A of the aerial system approximates that of the underground distribution system, the distribution circuits shall be designed to transmission line standards to protect the line or lines from the usual causes of outage to aerial distribution lines. Each end of the aerial circuits shall be equipped with the station class of metal oxide surge arresters, and automatic reclosing features shall be incorporated into the design. The routing of aerial distribution lines shall be selected to prevent a single destructive event from causing damage to the two or more distribution lines.

d. Administrative and other types of non-essential support facilities shall be supplied power directly from the primary substation. However, the design shall permit those facilities to be supplied by on-site generators if needs so dictate. The choice of power source for these loads shall be made on an individual site basis. Protective fuses and relays shall be used to prevent tripping of the on-site power source or feeder breakers when faults occur on non-essential support facility feeders. Protective devices shall respond to the true RMS value of current.

10-8. Facility electrical distribution system

The facility electrical distribution system distributes power from the off-site power supply and the on-site generating units to the various operating loads and facilities at the C4ISR site.

a. Power system switchgear shall be arranged in a multiple bus configuration. For the large and medium capacity power systems, the two main switchgear assemblies shall be installed in separate rooms so that a fire or explosion cannot damage both assemblies. The switchgear shall contain an exterior connection for the deployable power generation and distribution system (DPGDS) to supply electrical power when requested.

b. Breaker-interrupting capacity shall be adequate to interrupt the maximum symmetrical fault current available from incoming power lines, from the total number of generators, and from motors rated at or above 50 horsepower. Circuit breakers shall respond to the true RMS value of current.

c. The application of protective relaying shall follow the guidance of IEEE 242. Generally, this specifies differential relaying for transformers 5 MVA and above, and for all generators except single isolated machines having very small kVA rating. Bus differential and frequency relays shall be provided for each switchgear assembly. They shall be properly coordinated with protective relays provided for the protection of the commercial power source(s), on-site generators, and interior distribution feeders; and with protective fuses, relays, or circuit breakers on the load side of the medium-voltage switchgear assemblies. Feeders that originate at the circuit breakers in the two switchgear assemblies shall be protected with high-speed ground fault and instantaneous and time-overcurrent relays as necessary to ensure proper coordination with the bus differential relays and related protective devices. A coordination study shall be done to verify coordination of protective devices in the power plant switchgear with protective devices "downstream" of the switchgear.

d. For large capacity power systems, breaker pairs (see figure 10-4) common to the commercial power feeder(s) shall be used for synchronizing the on-site and off-site power sources. The breakers shall be rated to carry the total peak load currents and shall be electrically interlocked to prevent closure of both breakers unless bus one and bus two are synchronized. Breaker pairs common to the generators and those common to distribution feeders shall be electrically interlocked to prevent both breakers from being closed at the same time.

e. Direct current power shall be supplied from the 125 volt station battery system. Figure 10-7 depicts a system which might be used for a large capacity power system. Station batteries shall be lead-acid flooded type. Separate dc station battery power circuits shall be provided for the functions associated with commercial power, generating units, and distribution feeders. Branch circuit protective devices shall be installed in each breaker cubicle, compartment, or unit to provide separate branch circuits for breaker close and trip and for breaker motor charging functions.

10-9. Unit substations

C4ISR facilities shall typically be supplied from indoor type, double-ended secondary unit substations, with the exception of small capacity systems, which shall typically consist of unit substations only. Figure 10-8 (from TM 5-811-1, chapter 1), shows the preferred arrangement for a double-ended substation. An independent power service to each of the substation incoming line sections shall be provided. The normal mode of operation shall be with the two transformer main secondary breakers closed and the tie breaker open. Interlocking shall be provided to prevent the bus-tie (BT) breaker from being closed unless one of the main breakers is open.

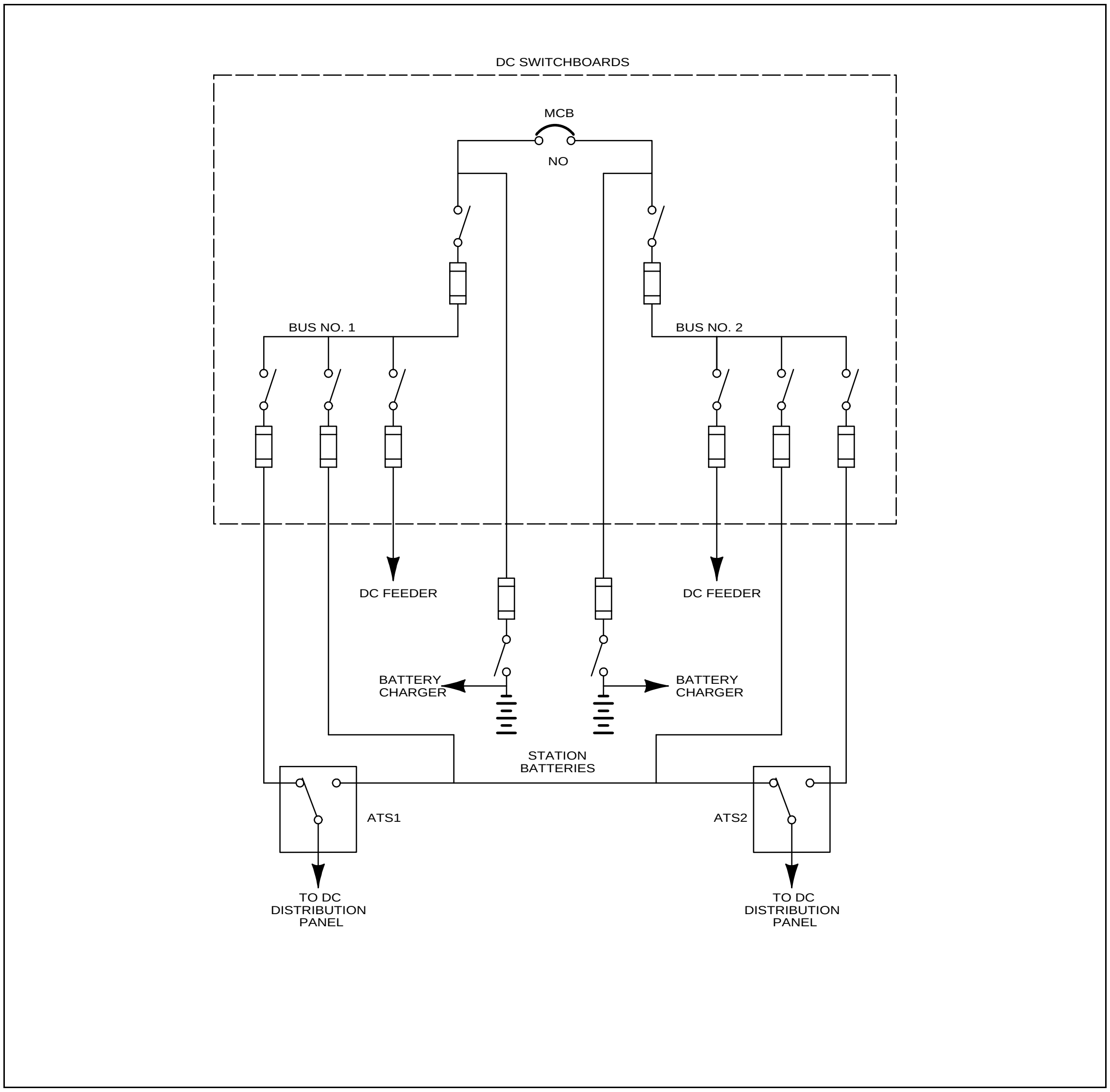

Figure 10-7. DC power distribution

a. Secondary transformers shall be non-ventilated dry type, or a sealed type. Secondary transformers shall be equipped with primary side surge arresters. Secondary transformers shall be equipped with a minimum of four 2.5 percent taps below and a minimum of two 2.5 percent taps above transformer nominal primary voltage rating unless otherwise indicated by the using government agency. Conventional transformers shall be derated, or K-factor rated transformers shall be used. The derating of transformers may be calculated by using either method given in IEEE C57.110, IEEE Recommended Practice for Establishing Transformer Capability When Supplying Non-Sinusoidal Load Currents. Derating methods that compare the crest factor of the load current to that of a purely sinusoidal waveform may underestimate the effects of higher order harmonics and shall not be used. Isolating transformers shall be used for supplying computer rooms and other non-linear loads and shall be K-rated. The recommended type is a power distribution unit (PDU) consisting of a delta-grounded wye isolation transformer and circuit breaker panels. Dry type transformers used to supply non-linear loads shall have impedance below six percent, preferably in the range of three to five percent as calculated at the nominal frequency. Three-legged core construction shall be used. Transformers serving computer and electronic

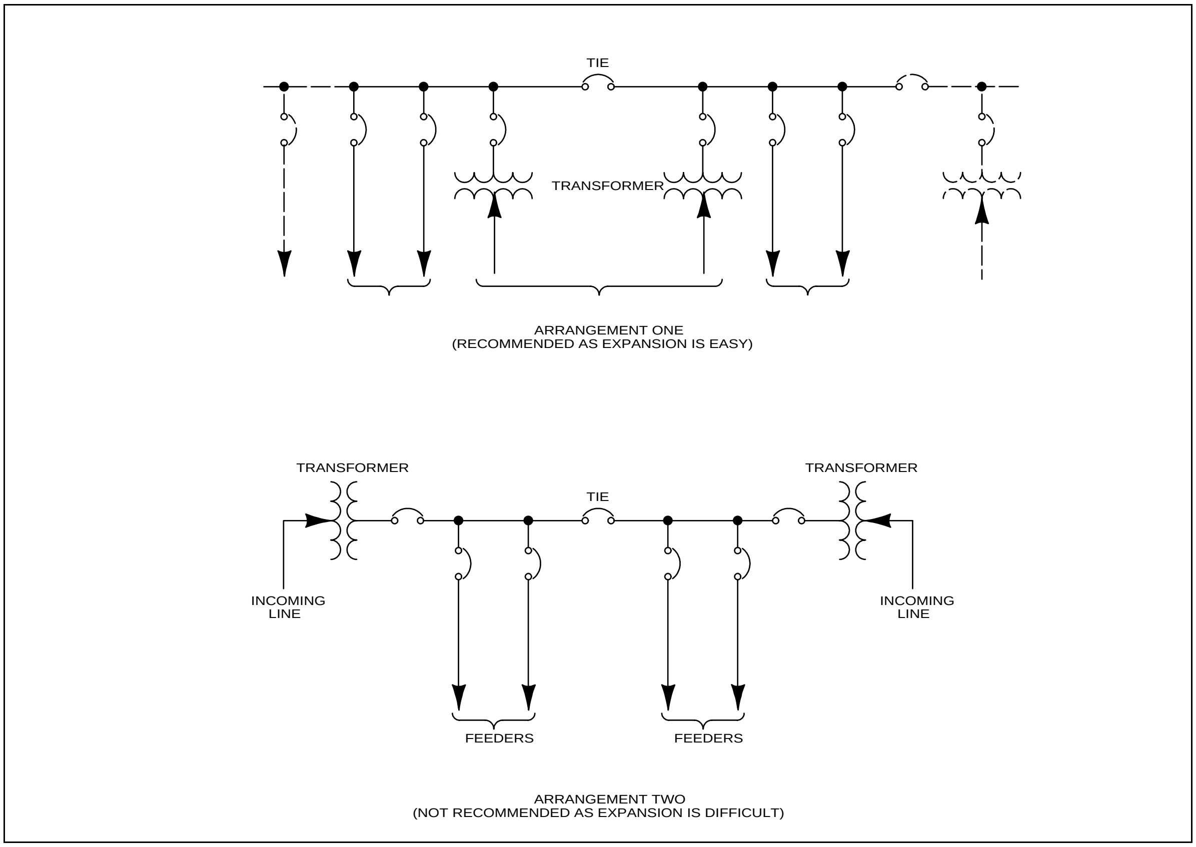

Figure 10-8. Double ended substation

loads shall be installed as close to the load as possible. Transformer-winding temperature sensors shall be provided and an over-temperature condition shall trigger local and remote visual and audible alarm signals.

b.   Switchboards shall be equipped with an equipment grounding conductor, bus-bar system. For 120/208 volt switchgears supplying load feeders, the neutral conductors shall have an ampacity greater than 2 times the ampacity of the individual phase conductors.

c.   Main and tie circuit breakers shall be the electrically operated drawout type. Feeder circuit breakers shall be the electrically operated drawout type when load demands exceed 225 amperes and feeders serve critical or essential loads. All breakers shall incorporate solid-state adjustable trip control elements. The main breakers shall be equipped with undervoltage trip devices having static time delay units. Local and remote indicating lights shall continuously indicate the open or closed status of each breaker. Automatic tripping of breakers shall be annunciated at the substation and in the CR. Circuit breakers shall respond to the true RMS value of current.

d.   If the substation is designed with common neutral conductors and a ground point at each transformer, either a modified differential scheme or a summation relaying scheme shall be used.

e. Unit substation main busses shall be provided with electronic power monitoring units. Functions provided shall include voltage, current, kilowatts, kilovars, kilowatt-hours, harmonics, etc. Units shall be capable of storing function data.

10-10. Motor control centers and distribution panels

Motor control centers, power distribution panels, and lighting distribution panels shall be provided with redundant breakers and buses and a bus-tie breaker when they serve critical loads required for maintaining operations under adverse circumstances. Under such circumstances, associated feeders shall be provided; these feeders, in conjunction with electrically operated circuit breakers, shall permit critical or essential functions to be performed to operate the C4ISR technical facilities properly. The primary feeder to each motor control center, power distribution panel, and lighting distribution panels shall originate from different unit substation buses. Non-linear loads shall be supplied from heavy-duty panelboards. For these panelboards, minimum line bus bar ampacity shall be based on full load plus 25 percent. The ampacity of the neutral bus-bar assembly shall be no less than two times the ampacity of the largest ampacity phase assembly. Panelboards serving computer and sensitive electronic loads shall be installed as close to the load as possible. Protective devices shall respond to the true RMS value of current.

10-11. Automatic transfer switches

Automatic transfer switches and associated bypass switches will typically be used in small capacity power systems. In general, transfer switches shall be of the electrically operated, mechanically held type, designed to provide automatic transfer of load from the normal power source to the alternate power source and to return the load to the normal power source on restoration of power. Transfer switches shall be of the double-throw type operated by a momentarily energized coil or motor mechanism and shall be positively locked on either source of power. Transfer switches shall be three pole except in systems using neutral switching. Four pole transfer switches shall be used where neutral switching is required (see paragraph 10-16.e.).

10-12. Interior distribution systems

Redundant feeders or branch circuit cables shall provide power to critical and essential loads and shall be contained in separate cable trays, conduits, or raceways routed along separate paths sufficiently remote from each other to prevent a single destructive event from damaging both power sources. Consideration shall be given to fireproofing cables in trays in areas where fires are likely to occur if routing through such areas cannot be avoided. TM 5-811-2, chapter 2, Electrical Design, Interior Electrical Systems, contains design guidance and guide specifications for interior distribution systems and other interior electrical work. The design agency shall specify separate feeders and branch circuits for computer and sensitive electronic loads. Loads that are sensitive to harmonics shall be isolated from those that produce harmonics. Isolation methods include transformers (including single-phase transformers serving single-phase loads), motor-generator sets, UPS, and power-line conditioners. A separate neutral shall be run to 120 volt outlet receptacles on each phase. Sharing of a neutral conductor for single-phase 120 volt outlets on different phases shall not be permitted. Protective devices shall respond to the true RMS value of current.

10-13. Lighting and receptacle systems

The design of the general lighting system shall be based on energy conservation. Circuiting shall be provided to prevent inadequate illumination in an area should a branch lighting circuit breaker operate to de-energize the lighting circuit.

a. Basic types and sizes of fixtures which can adequately illuminate the facility shall be specified for shop areas and general exterior and office environments of the facility. A standard set of fixtures for each of the major lighting types (fluorescent, incandescent, and high-intensity discharge) shall be specified.

b. Emergency lighting fixtures shall be located in the mission areas and where needed to adequately illuminate areas and equipment to be used to restore power following a complete electrical power outage in the C4ISR technical and technical support facilities. This system shall be in addition to conventional exit lighting. Locations housing emergency generators shall be provided with battery-powered emergency lighting. The emergency lighting charging system and the normal generator room lighting shall be supplied from the load side of the transfer switch. Both emergency and exit lighting fixtures shall be supplied from battery systems separate from the UPS batteries.

c. The illumination level throughout the CR shall not be less than 50 foot candles, except near cathode ray tube (CRT) type of equipment and near control panels where excessive glare would be detrimental to the visual acuity necessary under emergency conditions. Control panels or consoles shall be provided with canopies having integral lighting fixtures and dimmers necessary to obtain the proper level of illumination. General illumination levels near CRT type of equipment shall range between 15 and 25 foot candles, and shall be variable through the use of dimmers or dimming ballasts and controls.

d. Battery room lighting fixtures shall be vapor-proof and acid-resistant.

e. Receptacles of the proper type and rating shall be located throughout the C4ISR technical and technical support facilities as needed to facilitate operation and maintenance activities under normal and abnormal conditions. Receptacles necessary for operation under abnormal conditions shall be supplied from the UPS. Welding receptacles shall not be connected to the UPS.

10-14. Direct current systems

The dc system shall consist of separate batteries, switchboards, automatic transfer switches, and associated equipment similar to the UPS system equipment. Separate battery systems shall be provided to supply DC power to control circuits, exit and emergency lighting, and generator exciters.

a. The battery shall be rated for at least 125 percent of the peak load demand. Wet cells are generally preferred due to their longer life and the absence of the thermal runaway problem present with valve-regulated lead acid batteries.

b. The battery charger rating shall be consistent with the battery rating. The battery charger shall be supplied via a redundant pair of full-capacity feeders originating at the technical utility buses, and shall be switchable between the two sources. Non-liquid type batteries shall be equipped with cyclic chargers.

c. An adequately rated thermal-magnetic breaker or a fused load-break switch shall be provided at each battery to protect the battery output feeders. The breaker or fuse shall be rated to trip at battery full-load current. The time-current characteristics of the protective device selected shall be properly coordinated with other protective devices in the associated circuits.

d. A normally open, non-automatic type of circuit breaker or non-fused disconnect switch shall be installed in one of the dc switchboards to serve as a maintenance circuit breaker (MCB).

e. All switches shall be fused with dual-element, current-limiting type fuses. Peak let-through energy shall be coordinated with the fault current withstand ratings and the overcurrent ratings of the associated switches. Fuse ratings of the branch circuit switches in the inverter circuits shall be coordinated with the current inrush characteristics of the inverters. Fuses in the incoming lines from the batteries shall be coordinated with the short-circuit ratings of the batteries.

f. Instrumentation in the distribution switchboards shall include voltage sensors that initiate local and remote warning signals when the switchboard voltage exceeds the nominal equalizing charge voltage or when bus voltage drops to less than 90 percent of nominal.

10-15. Uninterruptible power supply (UPS) systems

An UPS system designed to provide continuous on-line high-quality power without excessive voltage or frequency transients shall be installed to serve as the power source for critical loads. The reliability and availability requirement of paragraph 2-4 shall be used as the electric power availability requirement (EPAR) for power at the technical load buses that supply critical loads. The same EPAR shall be established for critical support and essential loads when the characteristics of such loads are compatible with the critical loads. A separate UPS system shall be provided for critical support and essential loads if they are incompatible with critical loads because of different frequency or voltage ratings, excessive capacity, or operational characteristics and transient effects during starting and stopping operations. In such instances, the headquarters of the using government agency is authorized to establish a lower EPAR or electric power availability goal (EPAG) consistent with the degree of availability required to ensure continuous and successful completion of the site mission. Provisions shall be made during design to permit an increase, with a minimum of cost, in the capacity of the UPS systems should load increase substantially in the future.

a. The UPS system shall be fully redundant. It shall contain dual inputs, dual modules, and dual outputs. Figures 10-2 and 10-3 show a parallel-supplied redundant type of configuration that allows compatible loads served through the UPS buses to be continuously supplied following a failure of either one of the modules. The cold standby redundant (CSR) type of UPS system shall not be used.

(1) The UPS system herein described is required for the medium and large capacity power systems where a ventilated battery room is required. The smaller capacity (less than 250 kVA) power system may require only a system prepackaged by the manufacturer.

(2) The UPS system shall be an insulated gate bipolar transistor (IGBT) pulse width modulated (PWM) switching type unless the kVA size dictates a silicon-controlled rectifier (SCR) type unit.

b. Consideration shall be given to the use of such power-conditioning equipment (PCE) in lieu of using a UPS system when the purpose of that system is to minimize the effects of excessive transients known to exist on the utility power buses. The design agency shall consider these and other available types and incorporate the proper type into the design as warranted by design requirements for specific sites and projects. Installation of PCE in the input circuit to the automatic and manual maintenance bypass circuits shall be avoided.

c. The overvoltage and undervoltage curves of figure 10-9 (taken from IEEE 446, IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications) shall represent the boundaries to the ac output voltage of the UPS system. The power quality and performance specifications given in IEEE 446 shall apply as minimum requirements for the UPS system unless the data-processing equipment in the CR has conflicting requirements, or unless more stringent requirements are specified by the using government agency.

d. The UPS system shall be compatible with the loads to be supplied by the individual or multiple module systems. Modules shall contain self-protection features for protection from abnormal operating conditions on the input and output buses and of internal components. The starting and stopping, loading, and unloading characteristics of equipment to be supplied by the UPS inverters shall be compatible with the UPS inverter modules. The use of reduced-voltage starters shall be considered for motors with ratings and load characteristics that would cause the opening of the UPS output circuit breaker or the automatic transfer to the bypass mode of operation if full-voltage starters were used. UPS features that afford adequate protection against severe frequency and voltage transients on the input and output buses shall be specified in the procurement specifications.

e. UPS equipment rooms are required for medium and large capacity power systems and shall be located as close as possible to their associated battery rooms, adjacent to them whenever practical. Space or other constraints may necessitate locating switchgear, motor control centers, and panelboards remote from the UPS equipment rooms. In these instances, such equipment shall be located as close as possible to the UPS equipment room. When sufficient space is available, the UPS output switchgear shall be contained in the UPS equipment room. Any motor control centers and critical load distribution panelboards shall be located in the same room whenever space can be made available to accommodate the equipment. Consideration shall be given to housing the UPS input and output switchgear, any UPS output motor control centers, and the distribution panels or panelboards for critical loads in the UPS equipment rooms. Consideration also shall be given to combining the input switchgear with the generator bus switchgear when the generator voltage is the same as the input voltage to the UPS modules.

f. Each UPS converter or rectifier/charger shall be solid-state. It shall have sufficient capacity to supply the full rated load current to the inverter while simultaneously recharging a fully-discharged battery to 95 percent of rated ampere-hour capacity within ten times the discharge time after normal ac power is restored. The quality of the converter output shall be adequate to serve as acceptable inverter input with or without a connected battery as long as ac input voltage to the power supply unit stays within the limits specified in ANSI C84.1 and the input frequency is 60 hertz ±0.5 hertz. The ac input circuit breaker shall open and initiate local and remote alarm signals when there is an internal failure in the converter or when the battery has supplied current to the inverter for five minutes or more. If an internal exhaust fan is required for converter cooling, a redundant full-capacity fan shall be provided, and each fan's power supply circuit shall have independent overcurrent protection. The converter shall be interlocked with the battery room ventilation control system to prevent the converter from operating without proper ventilation.

g. Inverters shall be solid-state unless otherwise approved and shall be capable of accepting the output of the converter or battery and supplying the critical bus voltage and frequency. The inverter shall be capable of supplying an inrush current of seven times rated output current without damage or mis-operation. The inverter output frequency shall be "slaved" to the normal input frequency of the UPS converter. At other times, the inverter frequency shall be controlled by an internal crystal standard. The voltage variation at any steady-state load from 0 to 100 percent of the inverter capacity shall be within 0.5 percent of the rated voltage. The inverter shall be modularized. Semiconductor surge protectors shall be provided for the SCRs. The inverter shall have adjustable automatic limiting of current output. Performance specifications for inverters shall not be less than those given in IEEE 446. The inverter shall have the capability of compensating for output voltage when subjected to decaying battery voltage. If the output voltage cannot be properly regulated, then the inverter shall shut down. The inverter shall be equipped with self-protection against damage from an undervoltage on the input. More stringent requirements may be specified if warranted by the using government agency.

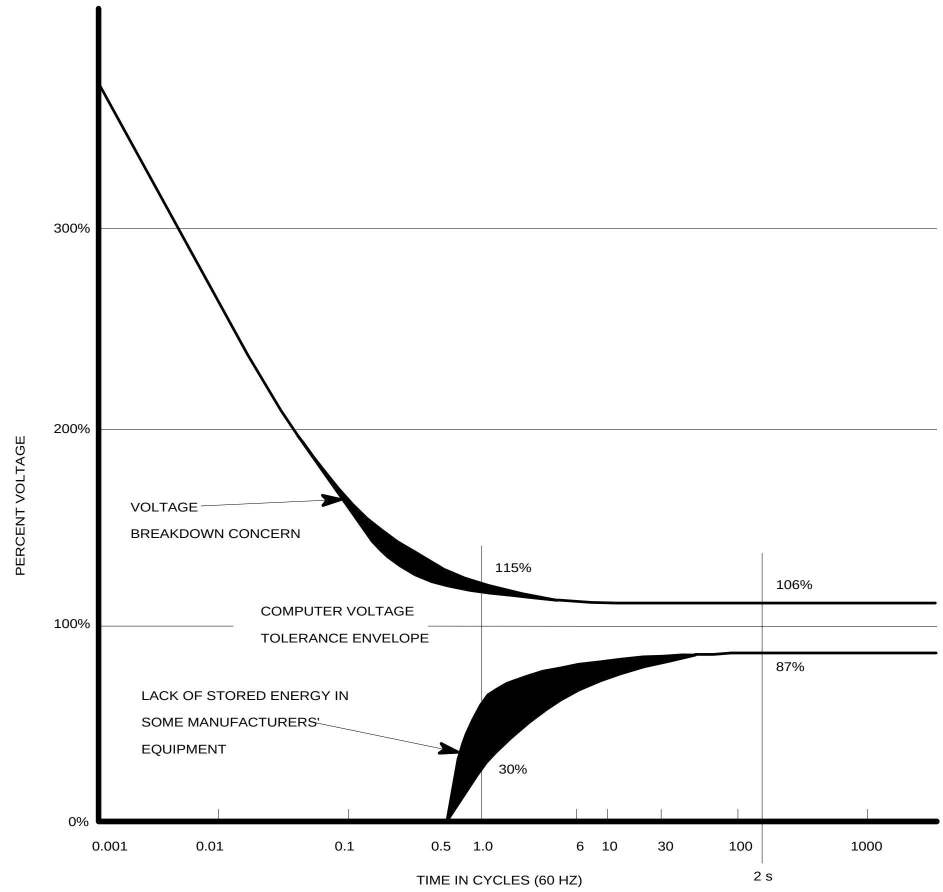

Figure 10-9. Typical design goals of power-conscious computer manufacturers
From IEEE 446 (Orange Book).

h. UPS switches of the static interrupter type shall be utilized unless the manufacturer's standard product incorporates the use of circuit breakers necessary for protection and isolation purposes. These breakers or switches shall be controlled by logic circuits in the UPS inverters or by other circuits included in a common control cabinet or panel. Signals so derived shall also cause closing of the static transfer switch when the monitoring circuits sense the failure of the inverter output or when the UPS module is driven into the "current limit" mode of operation for a preset period of time. Static transfer switches (STS) shall be specified to have control, interlocking, or logic circuits as needed to permit or prevent their closure as dictated by the operating mode of the UPS system. The speed of switching shall be such as to minimize transients on the UPS output bus and limit such transients within the frequency and voltage tolerances specified for the output of the UPS modules. In general, the static transfer switches should be specified to have a switching speed of five milliseconds or less. A switching speed of two milliseconds is obtainable in standard products of major manufacturers of UPS equipment and may be specified if consistent with the transient response time of the critical or essential loads.

i. The maintenance bypass switches or breakers shall be specified to have a make-before-break feature when such feature is required by the standard design of the UPS manufacturer. Logic or interlock circuits shall be provided as necessary to prevent switches from being closed when the buses that supply the module, static transfer switch, and maintenance bypass switch are not synchronous. Maintenance bypass switches shall be the electrically operated type and shall have provisions for manual operation and locking in both operating positions. In medium and large systems the tie control scheme shall allow momentary and continuous operation of the tie between the load side of two UPS as shown in figures 10-2 and 10-3. Continuous operation will allow all critical loads to be placed on one UPS so the other UPS can be serviced.

j. The ampere-hour capacity of the station service battery systems shall be based on an eight-hour discharge rate. The ampere-hour capacity of the UPS battery system shall be based on a 15-minute rate or duty-cycle. The capacity of the batteries shall be increased as necessary to suit load growth by the future addition of new equipment or new mission requirements. The UPS design shall be flexible enough to permit one battery bank to serve as an active source of power to one UPS module and as a standby source of power to the other module. One battery bank shall be supplied for each module in a parallel-supplied redundant UPS system. Breakers shall be provided at the UPS modules if required for safety or for operational considerations. The design agency shall consider the recommendations of the UPS system equipment manufacturer in this and other regards prior to completion of the design.

(1) The cell type batteries supplied shall be lead-acid, flooded type (wet cell).

(2) Ampere-hour capacity of the UPS batteries shall be calculated by plotting estimated battery load current for the 15-minute duty-cycle against time, showing a continuous 15-minute load. Adequacy of the battery selected shall be verified by starting the calculations at the beginning of the discharge cycle and subtracting the ampere-hour energy removed by each load increment to determine whether enough capacity remains for the final load increment. Battery voltage at the end of the duty-cycle shall not be less than indicated in IEEE 446, unless the UPS manufacturer stipulates a different voltage.

(3) A 25 percent derating factor shall be applied to provide for the normal decline in battery capacity due to aging of plates. In addition, a derating factor recommended by the battery manufacturer shall be applied, as applicable, to compensate for reduction in battery capacity that occurs when the ambient temperature in the battery room is less than 25°C (77°F). For temperatures above 25°C the resulting increase in available capacity will be treated as part of the overall design margin, as recommended in IEEE 485, IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications.

(4) The battery rack shall be designed for compatibility with the seismic environment in which it is located, and shall be appropriately finished to resist corrosion by battery chemicals.

(5) The station service and UPS batteries shall be isolated in separate battery rooms which shall be ventilated in accordance with chapter 7. The ventilation system shall include sensors for initiating alarm signals to a central alarm station in the event of ventilation system failure. Reference paragraph 10-13 for type of lighting fixtures to be considered for the battery room. Location of the UPS battery room or rooms will be adjacent to the UPS equipment room or as close as feasible to that room. The station battery room shall be located in a central location to supply the station service loads.

k. Alarm, control, instrumentation, battery status, and UPS status shall be provided in the CR. Each of the UPS modules shall have indicating lights or other means of clearly indicating the on/off status of each converter and inverter, and the status of each static transfer and UPS switch and maintenance bypass circuit. Indication of component status shall be provided in the CR for each UPS. The ac to dc converter unit shall incorporate meters both locally and at the CR for input voltage, input current, and output voltage, and an ammeter with zero at midscale for indication of charging or discharging modes of operation. The inverter assembly shall include meters for output voltage, output current, and frequency both locally and at the CR. All meters displaying electrical measurements in RMS values shall read true RMS values.

10-16. Grounding system

Grounding systems for conventional installations, including commercial power lines and substations, are specified in TM 5-811-1, Electrical Power Supply and Distribution, and TM 5-811-2, Electrical Design Interior Electrical Systems. Proper grounding methods for the safe and satisfactory operation of power, data processing (electronic equipment), and communication systems is also discussed in MIL-HDBK-419A, Grounding, Bonding, and Shielding for Electronic Equipment and Facilities. All metallic objects such as enclosures, raceway/conduits, equipment grounding conductors, and all earth-grounding electrodes shall be solidly bonded together with a continuous electrically conductive system. The metallic systems, such as the cold water piping system and the structural building steel system also shall be solidly interconnected to the service entrance electrical system. The grounding design and installation shall conform to all applicable codes and standards. These include NFPA-70, National Electrical Code (NEC); IEEE 142, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems; IEEE 1100, IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment; and Federal Information Processing Standards (FIPS) Pub 94, Guideline of Electrical Power for ADP Installations.

a. C4ISR facilities shall have an external grounding system, including a grid-type earth ground to be a part of a unified ground system. All exterior metallic components which penetrate the building, such as metal piping, conduits, and ducts, shall be grounded at the point of penetration. This system shall serve to ground all ordinarily grounded systems, such as generator and transformer neutrals or neutral impedance devices, electrical equipment enclosures, conductor shields, and the lightning protection system. The maximum resistance to ground of this system shall be ten ohms.

b. Each electrical room within the C4ISR facility which contains electrical equipment shall be provided with a ground bus, which shall be connected to the unified ground system.

c. AC power distribution systems shall have the neutral conductor grounded at the distribution transformer and to the earth electrode subsystem of the facility. The size of the ground conductor from the first service disconnect means to the earth electrode subsystem shall be as specified in Table 250-94 of the NEC. In each facility served by a common distribution transformer, the neutral shall be directly connected to the nearest point of the earth electrode subsystem. Where delta-wye systems conversion is employed, the service entrance shall be a five-wire system consisting of three phases, a ground (green) conductor, and a neutral. In each facility, all power distribution neutrals shall be isolated from the equipment case and the structure elements. The fault protection subsystem grounding (green) conductor shall be installed in accordance with table 250-95 of the NEC for all equipment. Conduit shall not be used as a grounding conductor.

d. The power system grounding shall ensure that all non-current carrying metal parts will be at the same ground potential, and that a low-impedance path is provided for fault currents. The selection of a grounding system shall be based upon magnitude of fault current, transient voltages, lightning protection, and application of protective relays for selective ground fault protection. Table 10-1 shall be used as a guide for power system neutral grounding applications.

(1) Grounding of electrical power circuits shall follow conventional practices except as follows.

(a) The insulated neutral cables from the commercial power substation, from the distribution transformer neutral or neutral impedance devices, and from each generator neutral or neutral grounding device, shall connect to a single ground location at the point of entrance of commercial power circuits into the utility equipment vault.

(b) Each neutral service shall have only one connection to ground. The connection shall be made at the origin of the neutral service. In double–ended substations, the transformer neutral or any transformer neutral grounding device shall be connected to a common insulated neutral bus, and the bus shall be connected to the grounding system at only one common ground point in the building grounding system.

Table 10-1. System grounding sub-application

	POWER SYSTEM NEUTRAL GROUNDING			**ELECTRONIC AND COMMUNICATIONS EQUIPMENT GROUNDING**		
System Voltage and Loads	Solid Grounding	Low-Resistance Grounding	High-Resistance Grounding	Single-Point Grounding	Isolated/ Insulated Grounding	HF Ground (Multi-Point)
A. 600 V and Below						
1. Linear Loads	X		X[1]	X		
2. Non-Linear Loads						
a. Data Processing	X					X
b. Process Controllers	X			X		
c. Adjustable Speed Drives	X			X		
d. Healthcare Facilities					X	
e. Communications						X
B. 2,400 V - 15,000 V						
1. Linear Loads	X[3]	X[2]	X[3]			
2. Non-Linear Loads						
a. Adjustable Speed Drives	X					
b. Converters/ Rectifiers	X					

[1]Used where high reliability is required.
[2]Used where majority of loads are three-phase motors.
[3]Used where there are single- and three-phase loads.

(2) Electrical power systems that are used to supply phase-to-neutral loads shall be solidly grounded. The maximum ground electrode impedance value for different facilities, as listed in table 10-2, shall be used for the design of solidly grounded systems.

(3) Electric power systems that are used to supply three-phase loads will be low-resistance grounded. The resistance value shall be chosen to provide a ground fault current acceptable for relaying purposes.

Table 10-2. Ground electrode impedance applications

FACILITY	MAXIMUM IMPEDANCE
General Industrial	5 ohms
Chemical	3 ohms
Computer Data Processing	Less than 3 ohms
Small Substation (local distribution)	5 ohms
Large Substation (regional distribution)	1 ohm
Generating Station	1 ohm
Commercial such as Metallic Building, Homes	Less than 25 ohms

(4) The high–resistance grounded system shall be used when high reliability is required. The application of high-resistance grounding to low voltage power systems shall be limited to three-phase systems of 480 to 1000 volts where ac line-to-neutral loads are not served. Ground detectors shall be installed on all high-resistance grounded systems.

e. Where ground fault protection is provided on the normal source distribution system, and the system has interconnected neutrals with an emergency/standby system, the electrical system design should include consideration of the use of four-pole transfer switches and grounding the emergency/standby source as a separately-derived system. Without the use of four-pole transfer equipment there may be sensing problems with the ground fault protection circuitry and the possibility of nuisance tripping. Generally speaking, whenever a sensing function for ground fault current is required on either source, four-pole transfer switches should be specified. To accomplish a separately-derived ground system, the connection shall be made between the emergency/standby source using an insulated copper cable and connecting directly to the earth ground grid.

f. Grounding practices for electronic and communications equipment shall be in accordance with IEEE 1100, IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment. A signal reference subsystem shall be installed at each facility. Where units are distributed throughout the facility, the signal reference ground subsystem shall consist of an equipotential ground plane. Table 10-2 shall be used as a guide for electronic and communications equipment grounding applications. See paragraph 10-19 for grounding associated with electromagnetic interference/radio frequency interference (EMI/RFI) shielding practices.

(1) A low–frequency system shall be installed at facilities employing low–frequency signals and shall be isolated from all other ground systems including structural, safety, lightning, and power grounds. It shall be connected to the earth electrode subsystem at one point only (single point) and configured to minimize conductor path length.

(2) A high–frequency system requires an equipotential ground plane. The equipotential plane shall be installed under the equipment. Signal, control, and power cables shall be routed in close proximity to the equipotential ground plane with the signal and control cables separated from power cables as far as practicable. The equipotential plane shall be connected to the building structure shell and earth electrode subsystem at many points.

10-17. Lightning protection

Design guidance and requirements for lightning protection systems for conventional installations are contained in TM 5-811-3 (chapter 3) Electrical Design: Lightning and Static Electricity Protection; TM 5-811-6; and TM 5-785, Engineering Weather Data.

a. Extensions of commercial power transmission lines within the boundaries of the individual C4ISR site shall be protected by grounded overhead static conductors. The same principle shall be employed in the design of the subtransmission or distribution class of aerial power lines rated below 115 kV. To provide ample spacing of phase conductors and grounded overhead static wires, the distribution class of aerial lines shall be designed as though rated at 115 kV. Designs shall stipulate installation of station-class metal oxide surge arresters on aerial lines when they are to serve technical loads. A minimum of three surge arresters shall be installed at each line tap, at each line support structure (on opposite sides of each line tap), at each pole where an overhead-to-underground transition occurs, and on both sides of line-sectionalizing switches. Designs for aerial service entrance conductors for technical facilities shall incorporate surge arresters, surge-protective capacitors, and metal oxide varistors (MOV).

b. The C4ISR site primary substation transformer(s) shall be protected by an aerial lightning-protection system. When practical, transformers shall be installed within the zone of protection provided for the commercial power line(s).

c. C4ISR facilities shall be protected against damage from lightning through conformance with the requirements stipulated in the documents referenced in this paragraph unless more stringent requirements are imposed by the using government agency.

10-18. Communications and alarms

Communications, instrumentation, and control links shall be provided between the C4ISR site primary substation and the C4ISR facility. The instrumentation and control system shall permit remote control of the primary substation distribution breakers from the CR. The system shall permit the control of electrically operated circuit breakers in the C4ISR facility from either the CR or the switchgear room(s). The position of all low- and medium-voltage circuit breakers shall be displayed locally at the switchgear and remotely in the CR. Metering shall be provided locally and duplicated in the CR. Abnormal operating conditions shall be annunciated audibly and visually at the switchgear and remotely in the CR. The control system shall consist of a programmable logic controller (PLC) based supervisory control and data acquisition (SCADA) system.

a. The communications system in equipment areas shall be a high-quality voice-grade system designed to operate in an acoustically noisy environment. The primary communications link shall be a page-talk system that allows audible paging over a public address system as well as individual conversations on a selected party line. An administrative telephone system shall be provided for normal communications in the rest of the facility.

b. The fire alarm and detection system shall comply with NFPA 72, National Fire Alarm Code, and the current approvals issued by Underwriters Laboratories (UL), Factory Mutual System, or another nationally recognized testing laboratory. The fire alarm signaling system shall automatically initiate fire alarm signaling devices whenever an automatic fire detector is activated, a manual pull station is activated, or a water flow alarm signifying sprinkler activation is activated. The fire alarm system shall have a central annunciator for the facility that receives the alarm from the various zones in the facility and transmits the alarm to the central fire alarm receiving station or directly to the fire department. The system also activates all other devices that might be required (such as smoke control systems and audible or visual alarm signals). The system shall transmit a trouble alarm any time a condition occurs that warrants a trouble alarm. The system shall be capable of operating with a single break or signal ground fault condition in the signal-initiating or alarm-sounding circuits. To maximize reliability and continuity of service, dual sources of electrical power with automatic switchover to the backup source upon loss of primary power shall be provided for the fire alarm systems in accordance with NFPA 72. Where a computer system of any kind or size is used to receive or process signals, an UPS shall be provided in accordance with NFPA 72. The UPS system for the fire alarm system shall be separate from the UPS system for the electrical power service for the C4ISR operation.

(1) The Central fire station at each site shall be the primary interface point to the fire alarm system. This interface shall provide the means to indicate the location of alarms which may be activated at the site and to signal the status of alarm supervisory and monitoring circuits. A secondary interface duplicating these alarm and supervisory signals may be provided where appropriate at another location. Fire alarm systems may be used to control functions other than alarm initiation and firefighter notification. These functions may be fire or non-fire related such as local evacuation signals, equipment or process shutdown signals, elevator capture, and activation of automatic fire suppression systems. However, the design shall be such that a fault in the external control function shall not prevent the normal operation of the fire alarm system. Examples of special interfaces are:

(a) Fire barriers between enclosures or operating areas may be needed to prevent the spread of fire. These barriers may need to be open during operations. An automatic closing interlock with the fire detection system will be required to close the barriers upon detection of a fire.

(b) In some areas, high-voltage transformers and switchgear may have to be de-energized when a deluge or sprinkler system is activated.

(c) Selected ventilation systems may have to be de-energized when a fire is detected within their zone of operation.

(d) Automatic shutdown of electric power may be required for computer-electronic data processing equipment in those areas where fire may operate sprinkler heads before manual shutdown could be accomplished. A manual reset shall be provided to re-energize the interrupted electrical system.

(2) The occurrence of any alarm, trouble, or supervisory signal shall be automatically transmitted to the central station equipment. Transmitted signals may be grouped into zones which define the localized area where the signal originates. All signaling line circuits shall be monitored for integrity. In addition to direct connection, either time or frequency division, multiplexing may be used for signal transmission. Alarms that respond to flow of water shall be provided wherever a sprinkler system is installed. These alarms shall comply with the requirements of the NFPA standard for the type of signaling system used. A manual fire notification method such as manual fire alarm boxes shall be provided and located in accordance with the appropriate NFPA standard. Combined watch reporting and fire alarm systems, if used, shall be in accordance with the appropriate NFPA standard.

(3) Automatic detection systems may be used to supplement or to actuate extinguishing systems. Detector spacing shall be in accordance with NFPA 72.

(a) Heat-actuated detectors (HADs) are appropriate when speed of detection is not the prime consideration, the space is small or confined and rapid heat buildup is expected, or ambient conditions do not permit the use of other detection devices.

(b) Flame-actuated detectors are appropriate when rapid detection is of prime importance in high hazard areas such as fuel-loading platforms, industrial process areas, high ceiling areas, and atmospheres where explosions or very rapid fires may occur. Since flame-actuated detectors must have a direct line-of-sight to the flame in order to operate, the number of devices and their aiming must be carefully engineered. False trips from extraneous radiation sources are also possible. For the above reasons, use of this type of device shall require careful coordination among the fire protection engineer and the equipment manufacturer.

(c) Smoke detectors shall be installed in all areas where required by the appropriate NFPA standard or by the authority having jurisdiction (AHJ). Smoke detectors shall be of a type operating on one of the principles described in NFPA 72. A mixture of detector types may be appropriate. Location and required spacing of smoke detectors shall be determined by the methods of NFPA 72. Spacing shall be based upon threshold fire size, fire growth rate, and ceiling height as described in these standards.

(4) The outside portions of fire alarm and supervisory systems shall comply with the latest revisions of NFPA 72; NFPA 1221, Installation, Maintenance, and Use of Public Fire Service Communication Systems; and ANSI C2, National Electrical Safety Code, as appropriate for the location. Outside cable installations for fire alarm and supervisory systems shall comply with the standards for telephone cable systems. Where poles are jointly used for electric power distribution and for supporting fire alarm and telephone cables, fire alarm cable shall be placed below the telephone cable. Fire alarm cables which are installed in underground ducts shall be distinctively marked within manholes that are shared with other communications cables and shall be kept physically separated from all power conductors. Exterior fire alarm pull boxes and emergency-reporting telephones shall be installed in weatherproof housings manufactured specifically for the mechanism.

(5) Auxiliary shunt trip circuits shall conform to the requirements of NFPA 72, unless a manufacturer's recommendation modifies these requirements. All equipment connected to auxiliary loops shall be listed for service under NFPA 72 rules. Fire detectors and other alarm initiating devices shall be connected in a fail-safe configuration.

(6) All means of interconnecting equipment, devices, and appliances in new fire alarm systems shall be monitored for integrity. Allowable exceptions to this requirement shall be as noted in NFPA 72. Existing circuits that are not monitored for integrity shall be subject to periodic tests and inspections at a more frequent rate than for monitored circuits. Monitoring integrity of circuits may be by ac or dc or through digital methods, with continuous line monitoring equipment suitable to detect a short circuit, open circuit, or unintentional ground fault. Devices for alarming detection of faults in all monitored circuits shall be located in the central station.

(7) Provision shall be made for supervising all those system components and conditions where abnormalities may adversely affect the performance of the fire protection system. Sprinkler systems shall be supervised in accordance with NFPA 72. Any alarm or fire-related auxiliary device, including fan bypass switches, which require manual resetting after operation, shall provide an audible and visible indication at the central station when in the non-reset position.

(8) Each new building or facility shall be provided with an emergency notification system (ENS) for announcing fire alarm informational and evacuation messages. A public address (PA) system may serve as the ENS for new or existing buildings if approval for such use is granted by the using Government agency. ENSs used for this purpose shall be in accordance with NFPA 72.

10-19. Electromagnetic interference/radio frequency interference

Effective shielding to limit EMI and EMP to within the required limits for C4ISR facilities is dependent upon the grounding and bonding practices required to provide a unified facility ground. The grounding practices for the earth electrode system, the building structure, the lightning protection system, the power system, and the signal reference system must be integrated to achieve a unified ground system. The particular grounding practices for each of these subsystems are illustrated in MIL-HDBK-419A, Grounding, Bonding, and Shielding for Electronic Equipment and Facilities. Additionally, specifications and installation designs for new equipment shall include requirements to assure electromagnetic compatibility (EMC) between the equipment and the operating environment. These requirements shall serve to minimize the susceptibility of the new equipment to EMI that may be present in the operating environment as well as to limit radiated emissions by the equipment to the environment and to existing equipment.

10-20. Personnel and electrical system protection

Electrical systems, both interior and exterior, shall be designed to prevent injury to personnel and damage to equipment. The design for personnel and system protection shall be in accordance with appropriate sections of NFPA 70 and these criteria.

a. Where unusual circumstances in the use of low voltage present a shock hazard to personnel from possible line-to-ground contact, ground fault circuit interrupter (GFCI) devices shall be installed to supplement, but not replace, the normal system protection devices.

b. System protection shall comply with IEEE 242. Protection for systems shall be designed to limit damage to equipment and to minimize interruption of power consistent with reliability of power required by the loads.

c. Protective devices shall be coordinated to achieve sequential operation of fault-clearing devices from the load or fault toward the source. Differential protection should be provided when the cost for the protection would be less than the cost of the equipment damage that it could prevent. Where differential protective relaying is used for generator, motor, or transformer protection, the generator load breaker, the motor feed breaker, and the transformer secondary breaker (as applicable) shall be included in the differential zone. Where bus differential protection is used, circuit breakers on the bus shall be included in the differential zone. Exceptions will be noted. The design shall include exact settings for all protective relays.

10-21. Cathodic protection

Underground metallic process piping and vessels shall be cathodically protected where required by the specification for a facility. Cathodic protection systems shall be designed by a NACE-accredited corrosion specialist. Suitable drawings shall be prepared to designate the overall layout of the pipe lines to be protected and the location of significant items of structure hardware, corrosion control test stations, electrical bonds, and insulating flanges and couplings. Design requirements shall be governed by the National Association of Corrosion Engineers (NACE) RP0169, Control of External Corrosion on Underground or Submerged Metallic Piping Systems. For design and installation details, see TM 5-811-7, Electrical Design, and Cathodic Protection.

a. All natural gas, recirculating cooling water, hazardous chemical, or other designated metallic pipe lines shall be protected. Fire water mains may require protection depending upon the materials of construction utilized, the location of the main in the plant, soil samples taken at the plant site, and ground voltage gradients near the pipes.

b. Cathodic protection for underground flammable/combustible liquid storage tanks and piping shall comply with NFPA 30. The interior of aboveground steel water tanks shall be protected by a cathodic protection system when the calcium content of the water is less than 18 ppm or when the calcium content is between 18 and 55 ppm and the sulfate content is greater than 25 ppm.

c. Insulating devices consisting of flange assemblies prefabricated insulating joints, unions, or couplings shall be installed at the termination of service line connections and entrance piping to prevent electrical continuity with other piping systems. These devices shall be properly rated for temperature, pressure, and dielectric strength. Lightning and fault current protective anodes shall be installed at insulating flanges or devices.